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Abstract. Heat transfer and turbulence in channel flows past either a single rib or a rib array installed on the wall have been studied experimentally. It has been revealed that the local heat transfer coefficient behind a rib and a rib array is statistically closely related to RMS fluctuations of the vertical component of velocity in the near-wall region. This result points to a possible way to control the hydrodynamics aiming at heat transfer enhancement in turbulent flows in the channels with discrete roughness.

1. Introduction

Walls with discrete roughness elements intended for heat transfer enhancement decrease the thickness of thermal boundary layer by disruption and redevelopment of dynamical boundary layer in the near-wall region. Spanwise ribs, caverns and dimples are most frequently employed to that end. The history of heat transfer enhancement in ribbed channels can be found in review papers [1–4]. For a long time, the optimization of shape, size and spatial position of roughness elements has been the main approach to the enhancement of thermal-hydraulic performance of such channels.

Variation of channel geometry was aimed at the search for the most efficient configurations for the disruption or disturbance of the turbulent boundary layer resulting in thinning of the viscous sublayer and reduced thermal resistance of the near-wall fluid. However, the correlation between heat transfer parameters and hydrodynamics of separated flows is underexplored.

When studying the effect of discrete roughness on the flow, either of two approaches to the analysis can be adopted: detailed approach (structure of flow past roughness elements is analyzed) or averaged approach (only the profiles of velocity and turbulence in the boundary layer disturbed by the roughness elements are examined). An extensive review [5] stands out as far as the detailed approach is concerned. It is noteworthy that this review describes the flow structure around different types of discrete roughness only qualitatively with no reference (in most cases) to quantitative data. In the framework of the averaged approach, we should mention the review [6], which provides extensive information on the effect of roughness on the profiles of velocity and turbulence. Notably, the analogs of so-called sand roughness have been studied for the most part, and they are only remotely similar to the discrete roughness elements employed for heat transfer enhancement.

The present paper provides detailed information on the correlation between local heat transfer and local flow characteristics in the channel flow past a single spanwise rib or a wall roughened with an array of square spanwise ribs.

2. Experimental setup and procedure

The flow structure and heat transfer were experimentally studied in the channel with either a single rib on the wall, or an array of discrete roughness elements (figure 1). Square spanwise ribs with the height of h=9.5 mm were mounted in a 1.8-m long channel with a cross section of 150×115 mm. Two geometries were considered: a single rib installed at the distance of 1 m from the inlet and discrete roughness in the form of spanwise ribs covering the whole length of the bottom wall with a pitch p/h=10.

The airflow rate through the channel (280.0 m³/h) was maintained with the uncertainty of no more than 0.25% using the standard critical flow nozzles.
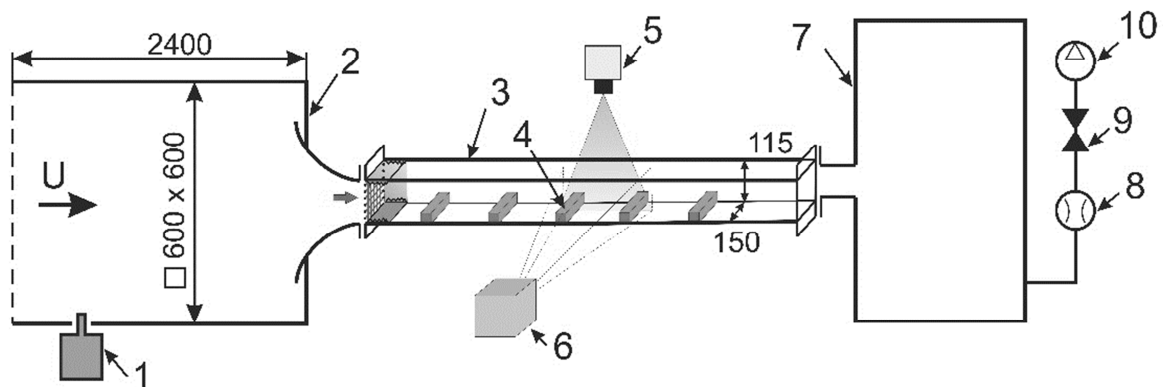
Figure 1. Schematic of experimental setup. 1 – smoke generator; 2 – smoke preparation chamber; 3 – test section; 4 – rib array; 5 – continuous laser; 6 – high-speed camera; 7 – receiver; 8 – critical flow nozzles; 9 – gate valve; 10 – air blower.

Local coefficients of heat transfer were measured using the method based on electrical heating of the wall and measurement of its temperature by one and the same element made of thin metal foil with a high temperature coefficient of resistance [7]. When studying heat transfer, we heated the bottom wall over its entire length in the regime of q=const. Detailed description of the measurement technique was provided in [8].

The dynamics of instantaneous fields of velocity was estimated from SIV measurements [9], which currently features high spatial and temporal resolution required for investigation of turbulent microstructure allowing for the energy of vortices of the order of Kolmogorov scale [10].

3. Results and discussion

Experimental data on heat transfer in the wake of a single rib and in the gap between the ribs (in the case of rib array; rib pitch p/h=10) are demonstrated in figure 2. The Reynolds and Nusselt numbers were based on the rib height as a characteristic dimension. Bulk velocity in a smooth channel (without ribs) was employed as a characteristic velocity in the Reynolds number estimation and when normalizing the fluctuations. The figure demonstrates that the distributions of heat transfer in the flow past the single rib differ from the rib array case with the most pronounced discrepancy documented at x/h>5.

A detailed flow structure and turbulent characteristics were obtained from SIV measurements for the same flow configurations. The bottom part of figure 2 demonstrates the profiles of streamwise and vertical fluctuations of velocity in the near-wall zone of the wake behind the single rib and between the ribs (in the case of rib array). The scales of turbulent characteristics are geometrically consistent with the x/h-axis of the upper graph. At the distance of approximately $0.1h$ from the wall, these fluctuations attain their maximum and remain constant further from the wall. Note that this finding is true only for the near-wall zone but not the shear layer far above that coordinate, where the

fluctuations level is much higher. RMS fluctuations of the vertical velocity component at the distance of $0.1h$ from the wall are plotted along with the heat transfer data for the two considered flow configurations.
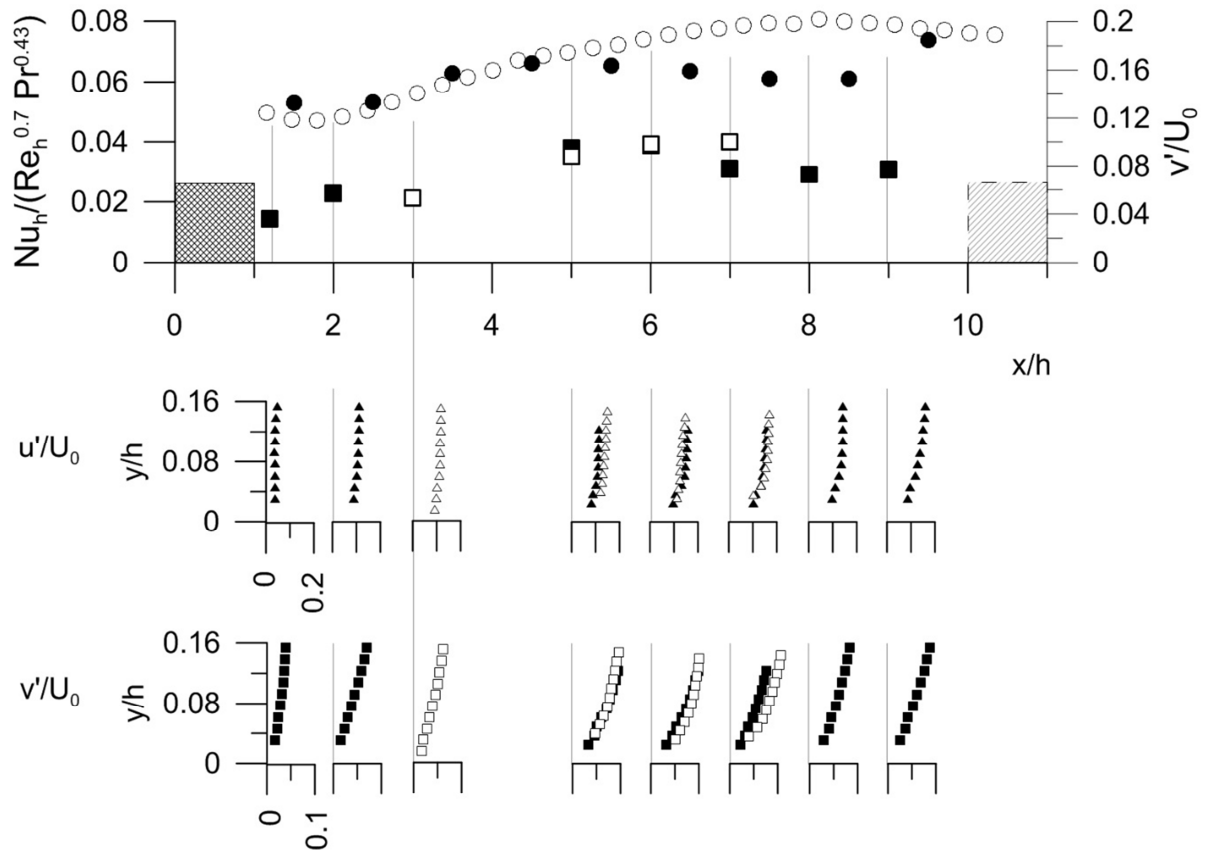
Figure 2. Behavior of the local heat transfer coefficient (circles), fluctuation intensity of streamwise (triangles) and vertical (squares) components of velocity in the wake of a single rib (open symbols) and in the channel with discrete roughness (solid symbols).

From the comparison of the local values of *Nu* and v'/U_0 it follows that they are almost proportional for both configurations in the whole measurement region. In other words, the local heat transfer coefficient behind both the single rib and a rib in the array is statistically closely related to the RMS fluctuations of the vertical velocity component in the near-wall zone. This pattern is likely to have a physical meaning consisting in the fact that heat transfer enhancement results predominantly from the increase in wall-normal velocity fluctuations. The obtained result points to the possible way to control the hydrodynamics aiming at heat transfer enhancement in the turbulent flow in the channel with discrete roughness elements.

4. Conclusions

Correlation between the local heat transfer coefficients and local hydrodynamics in the near-wall zone of recirculation region has been estimated. It has been revealed that local heat transfer in the

recirculation zone of the separation region is proportional to non-dimensional RMS fluctuations of the vertical component of velocity in the near-wall region.

Acknowledgments

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